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# Geology and Petrography of the rocks around Liji Area, Gongola Sub-basin Northern Benue Trough, Northeastern Nigeria

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## ABSTRACT
Geological mapping of Liji and environs show that the area is composed of Precambrian basement and Cretaceous sedimentary rocks. The basement rocks are represented by granite and pegmatite members of Pan-African granitoids whereas the sedimentary rocks consist of Bima Sandstone, Yolde Formation, Kanawa member of the Pindiga Formation and Gombe Sandstone. Petrographic investigation indicates that the granite consists of quartz, orthoclase, microcline, plagioclase, biotite and muscovite with accessory iron oxide and zircon. Pegmatite is composed of quartz, plagioclase, orthoclase and muscovite with accessory biotite while baryte occur as secondary mineral. Bima Sandstone consists of quartz, orthoclase, microcline with minor amount of biotite and iron oxide. Yolde Formation is composed of quartz, orthoclase, plagioclase, biotite with minor amount of iron oxide and zircon. Limestone unit

of the Kanawa Member of Pindiga Formation consists of calcite, dolomite, microcline, quartz and iron oxide. Gombe Sandstone is made up of quartz, feldspar and opaque ores.

**Keywords:** Pan-African, Granitoids, Petrography, Liji, Nigeria
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## 1. INTRODUCTION

The study area lies within Liji part of Gombe local Government area of Gombe State of Nigeria which constitute a portion of the Federal Survey of Nigeria sheet 152 Gombe NW and NE constituting part of the Gongola sub-Basin of the Northern Benue Trough (Fig. 1). The area consists lithologically of the Precambrian Basement Complex rocks and Cretaceous Sedimentary rocks. This study attempts to investigate the geology and petrography of the rocks around Liji area.

The Northen Benue Basin is divided into Gongola and Yola sub-Basins, where the Gongola sub-Basin is believed to be separated from Chad Basin by an anticlinal feature termed the Dumbulwa-Bage High (Zaborski *et al*., 1997). Sedimentation in the Gongola sub-Basin began during Aptian-Albian times and continued throughout Cretaceous period depositing piles of sedimentary rocks in succession, of varying lithologies and environments of deposition, that range from continental through marine to estuarine/deltaic. The stratigraphy of the Gongola sub-Basin of Northern Benue Trough is presented in Figure 2 while summary of the description of sediments is given thereafter from oldest to youngest.

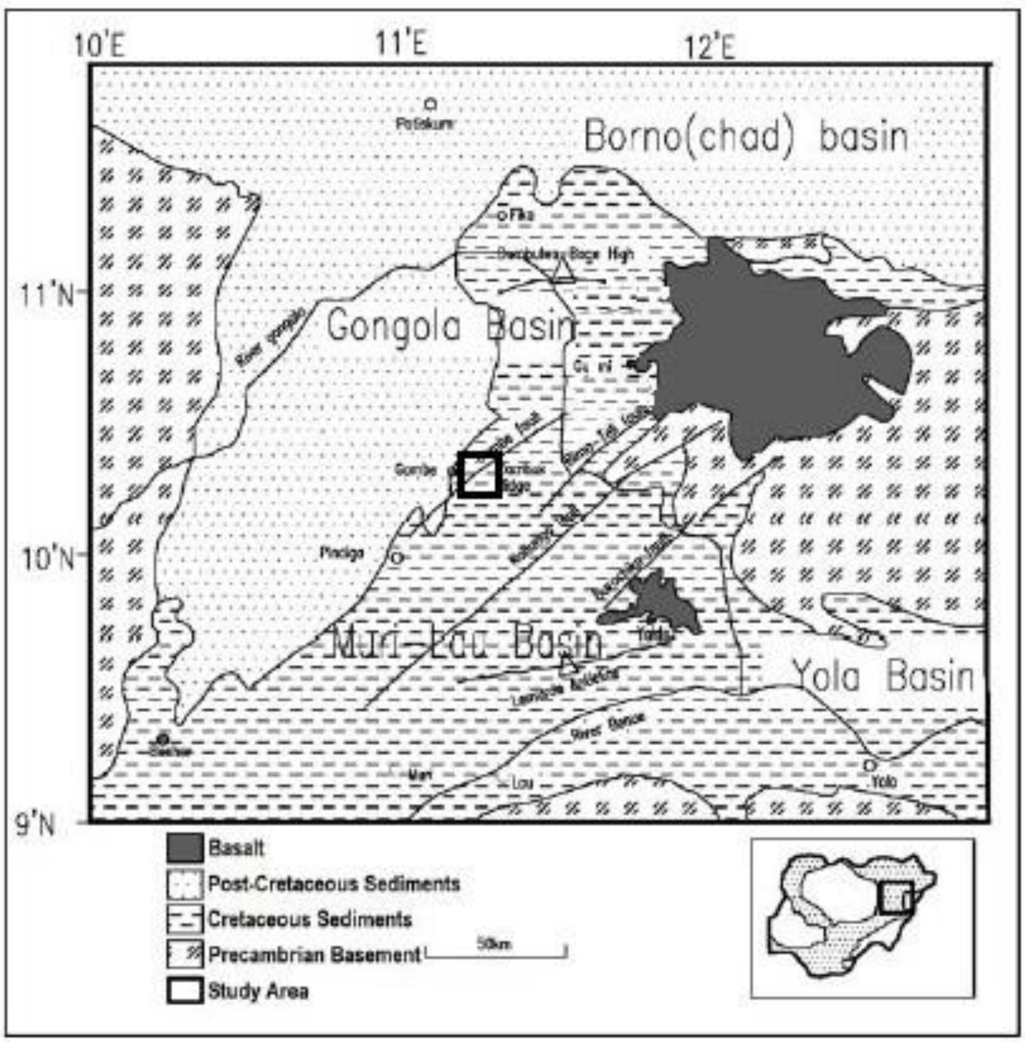


**Figure 1: Geological Map of the Northern Benue Trough showing the study area ( Zaborski, et al., 1997)**

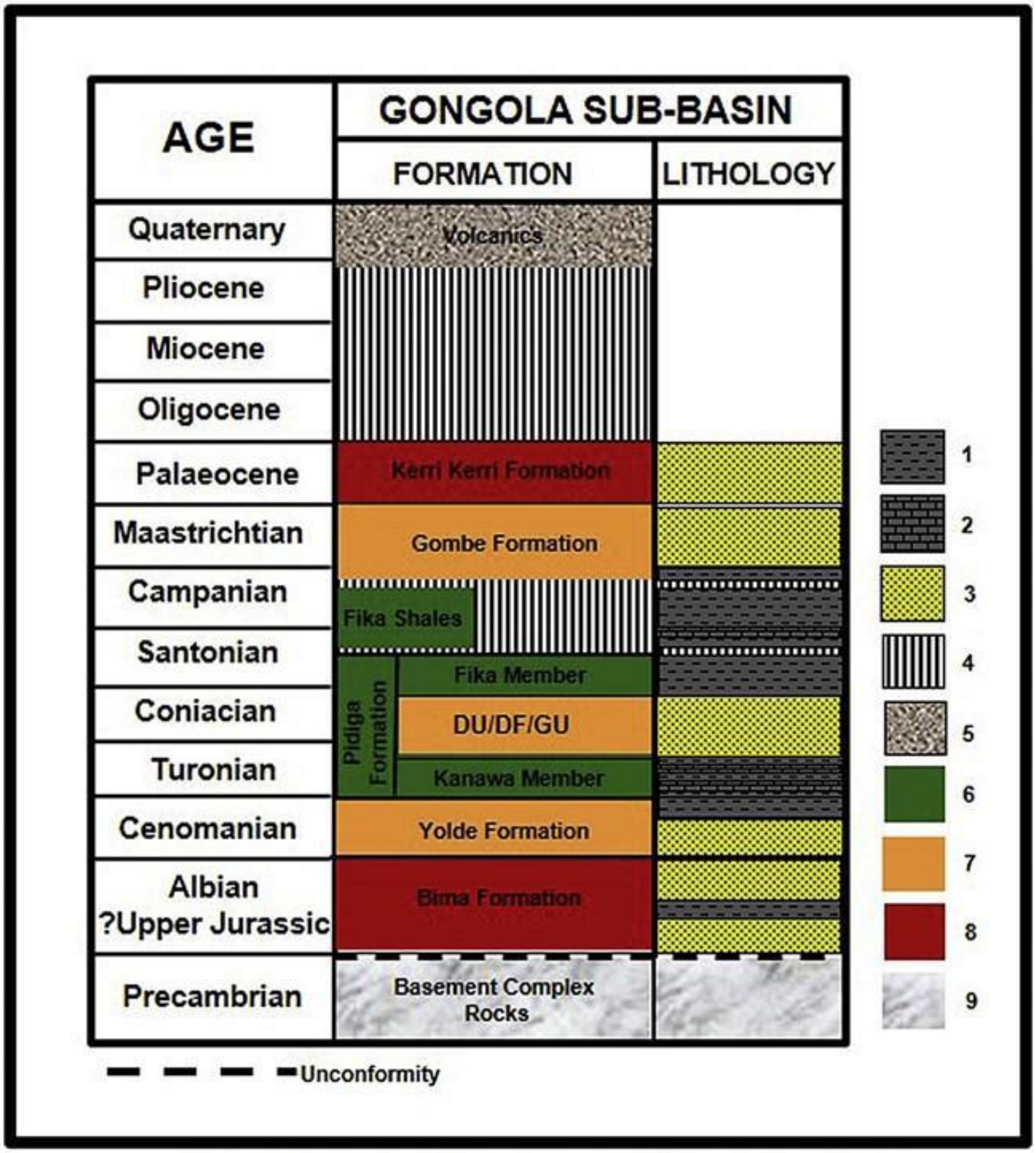


**Figure 2: Stratigraphy of the Gongola Sub-basin (After Shettima et al., 2018) 1-Mudstone, 2-Limestone, 3-Sandstone, 4-Hiatus, 5-Basalt, 6-Marine sediments, 7-Transitional marine sediment, 8-Continental sediments, 9-Basement complex (DU-Dumbulwa Member).**

The Aptian-Albian Bima sandstone, a continental formation represents the basal part of the sedimentary succession within Upper Benue Trough, which rest directly and unconformably on the Precambrian crystalline Basement Rocks and consists of three siliclastic members: the lower Bima (B1), middle Bima (B2), and upper Bima (B3) (Guiraud, 1991)). The Formation generally consists of massively bedded, sparsely fossiliferous, poorly sorted, medium-coarse grained arenaceous feldspathic sandstone. The Formation is mainly composed of sandstones, although the occurrence of shale intercalations have been reported (Avbovbo *et al*., 1986). The lithology is diverse, indicating accumulation under widely varying conditions, including fluviatile, deltaic and lacustrine depositional environments (Guiraud, 1990).

The transitional Yolde Formation marked the Cenomanian (Allix, 1983). This Formation represents the beginning of marine incursion into the Upper Benue Trough and Chad Basin. The Formation lies conformably on the Bima sandstone characterized by alternating sandstones, shales and dark grey mudstone which frequently displays dessication cracks. The sandstones are variable, usually coarse-grained and cross bedded, but sometimes regularly bedded with argillaceous intercalations (Nwajide, 2013).

The Turonian-Santonian Pindiga Formation conformably overlies the Yolde Formation in the Gongola Arm of the Northern Benue Trough and has been studied in greater detail. It consists of a sequence of marine shales which include limestone interbed

toward the base. The Formation contains a number of limestone beds termed the limestone-shale member at the bottom while the upper part consists of blue-black shale termed the shale member (Carter *et al*., 1963). Zaborski *et al*. (1997) subdivided the Formation in the Gongola arm into five members (from top to bottom) namely: the Fika member, Dumbulwa member, Deba Fulani member, Gulani member and Kanawa member, noting that the Gulani, Deba Fulani, and Dumbulwa members are lateral lithofacies equivalents occurring in the middle part of the Pindiga Formation.

The Kanawa Member corresponds only to the lower shale-limestone member of the Pindiga Formation that provide excellent stratigraphic mark horizon between sandy units above and below and a middle part consisting of shaly mudstones that are dark grey in colour when fresh but showing much lighter blue to green-grey colours in weathered zones with irregular thin lenses and discontinuous layers of diagenetic gypsum (Zaborski *et al*., 1997). The limestones underlie the shale units and have a varying thickness from few centimetres to a maximum of two meters. The upper surface of the limestones at times shows *Thalassinoides* burrows, reworked fossils, phosphatic matter, glauconite concentration and ammonites such as *Pseudaspidoceras* and *watinoceras,* as well as mollusc, echinoids and serpulids (Zaborski *et al*., 1997). The age of the abundant ammonite fauna in the limestone beds range from Late Cenomanian to Early Turonian which makes it possible for correlation of the Kanawa Member (Zaborski, 1998). The regressive conditions that set in during the middle Turonian in the Upper Benue Trough led to the deposition of arenaceous beds of the Gulani, Deba-Fulani, and Dumbulwa Members. They are mainly fluviatile sediments. The Gulani Member consists of thin bedded coarse and very coarse grained pebbly sandstone with purple brown and white laminated mudstone interbeds. The member typically shows very large scale tabular cross-bedding in coarse-grained sandstones and granulestones with frequent rippled-mark while the mudstone occasionally displays dessication cracks. The Gulani Member has a thickness of 230m in the Dogon Zaga area (Zaborski, 1998). Zaborski et al. (1997) proposed the name Deba Fulani Member for the sandstone unit occurring in the middle part of the Pindiga Formation and around Deba Fulani area. Exposures of this member are rare and no complete section located. Limited section shows sequence of sandstones, siltstones in beds of 5cm – 15cm thickness present in streams around Deba Fulani. It consist of well bedded coarse to medium grained sandstones with varying thickness ranging from 5cm – 1m and alternating with silty sand and silty shales. The Dumbulwa Member is the sandstone-shale unit corresponding to upper sandtone/shale member of the Gongila Formation of Carter *et al*. (1963). It contains coarse-grained, feldspathic tabular cross-bedding sandstones, channel filling sandstones, thinly bedded fine-grained sandstones and laminated silty sandstones. The member reaches its greatest thickness of about 200m in the Dumbulwa and Bage Hills. The Fika member comprises black shales, silty and sandy shales, siltstones and fine-grained sandstones with carbonate beds at various levels. It was believed to represent a period of non-stop deposition from Turonian to Maastrichtian (Carter *et al*., 1963; Lawal, 1982). Zaborski (1998) believed that the Fika Member may represent two distinct depositional episodes separated by the Santonian compressional event, comprising the Pre-Campanian part primarily consisting of shales indistinguishable from those of the Kanawa Member and the lower part, thought to be Upper Turonian to Conacian. The upper part has been dated with certainty to be late Campanian to early Maastrichtian and a variable thickness of about 600m has been reported (Lawal, 1982; Lawal and Moullade, 1986).

Cretaceous sedimentation in the Gongola sub-basin ended with the deposition of Gombe Sandstone. The late Campanian cycle of rifting continued up to Maastrichtian during which Gombe Sandstone was deposited (Guiraud, 1983). The Gombe Sandstone consists of rapidly alternating thin beds of silty shales, fine-to-medium grained sandstones with some intercalated flaggy ironstones regarded as estuarine to deltaic deposits (Carter *et al*., 1963). According to Zaborski (1998) the general coarsening upward nature of the Gombe Sandstones, its lateral facies distributions, presence of coal and the disappearance of marine micro fossils in the upper most Fika Member point to an overall prograding origin. The Gombe Sandstone has thickness of 300m.

The Cretaceous sedimentary rock of the Gongola sub-basin was partly concealed by the Tertiary Kerri-Kerri Formation to the west in the Gongola Arm of the Upper Benue Trough and south-western part of the Chad Basin.

The Kerri-Kerri Formation unconformably overlies the Gombe Sandstone and represents the youngest sediment in the Gongola Arm. The Formation consists of a continental sequence of flat-lying to gently dipping grits, sandstones and clays. It is capped with thick ironstone which may be oolitic or vesicular textured in most outcrops (Obaje, 2009). The type section is exposed at Kadi with maximum thickness ranging from 300m – 320m. The age of the Kerri-Kerri Formation is Paleocene (Carter *et al*., 1963; Adegoke *et al*., 1986).

## 2. METHODOLOGY

### 2.1 Geological Mapping

The Liji area was mapped on a scale of 1:50,000 using the topographic maps as base maps. A total area of about 144 $Km^2$ was covered using traverse compass mapping technique. Equipment used include compass-clinometer, geological hammer, Global Positioning System (GPS), digital camera, measuring tape, field note book, pen, pencil, indelible marker, masking tape, acid bottle,

sample bags, and topographic maps. Representative rock samples where outcrops are exposed were chipped, described on the spot as hand specimen. Samples were then labelled, the locations (exact coordinates of sample points in terms of latitudes and longitudes) noted and plotted on the base map with the aid of the GPS.

### 2.2 Petrography

A total of 38 rock samples were thin sectioned following the method of Kerr (1977). The thin section preparation involved cutting a thin slice from the rock samples using cutting machines. The slices were polished with abrasive powder until a required level of polishing was attained. The polished surfaces of the slices were then mounted on the glass slides using araldite. The glass slide with the mounts were placed on the hot plate and heated for 10 minutes. The samples were removed from the hot plate and allowed to cool. The slides were once more polished to standard thickness of 0.03mm using abrasive powder on glass laps. Canada balsam drops were smeared on the glass slides while on the hot plate and very thin glass covers were placed on the finished polished surfaces in which gentle pressure were applied to remove trapped air bubbles as well as excess Canada balsam. The slides were allowed to cool, harden and the overflow of the balsam was washed off using organic solvent. The slides were then properly labelled and subjected to petrographic studies using petrological polarizing microscope.

## 3. RESULT

### 3.1 Basement Complex Rocks

The Basement Complex rocks that outcrops in the Liji area constitutes about 7% of the mapped area (Fig. 2). The Basement rocks occur at the extreme south western corner and south central portion of the mapped area. The basement rocks are represented by granites and pegmatites members of the older granite suites.

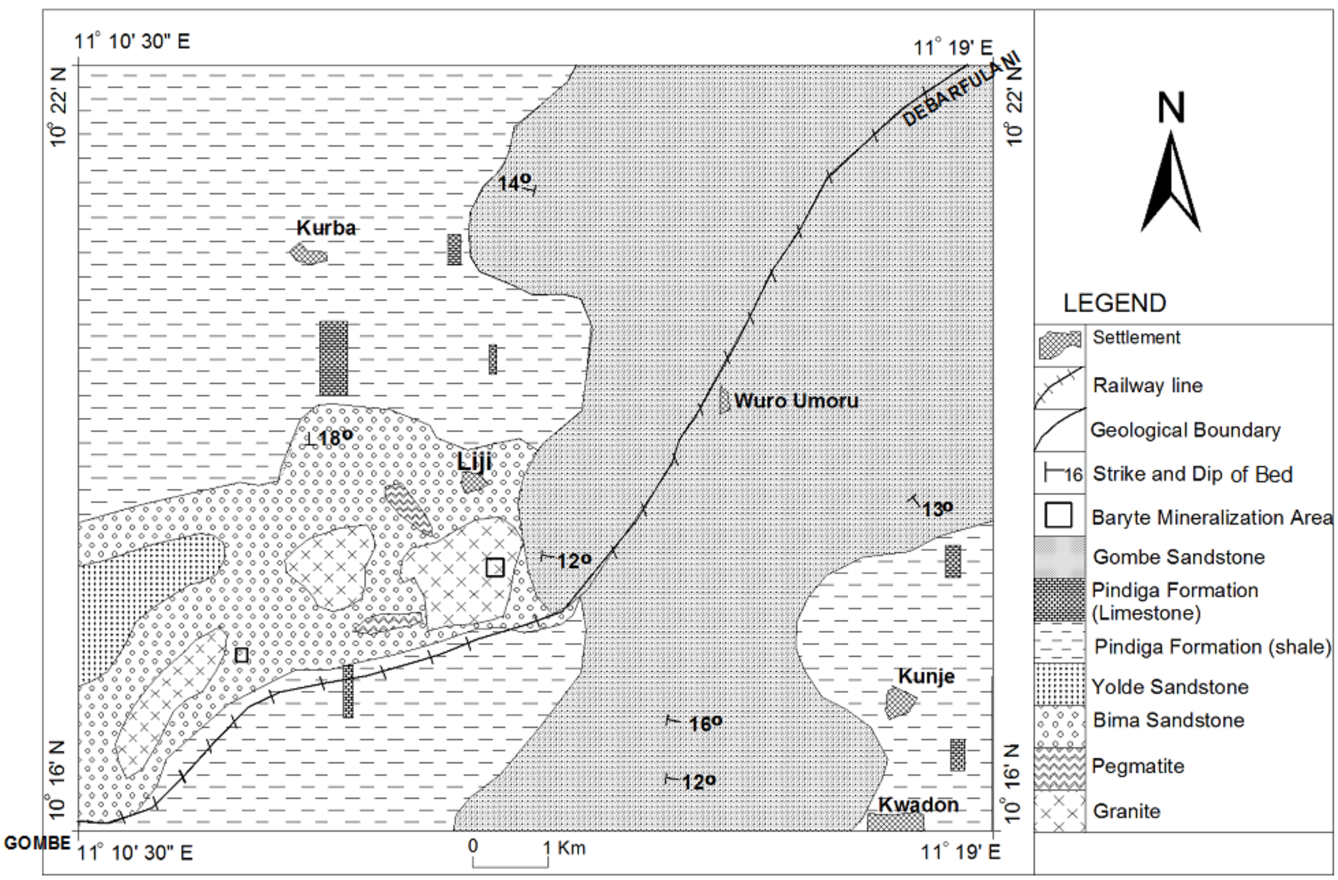


**Figure 3: Geological map of Liji area**

***3.1.1 Granite***

The rock is located 1km south of Liji in the south-central part of the mapped area, and also about 6km south-west of Liji (Fig.3). The rock appears in variety of colours that ranges from pink, brown, gray and dark. The rock is massively granular, medium to very coarse grained textured and occurs in form of hills with numerous boulders and fragments due to action of weathering. The granite is nonconformably overlain by Bima sandstone (Plate 1). In hand specimen the rock is composed mineralogically of quartz, feldspars, biotite and muscovite. Quartz veins of varying widths have been observed. About 4 baryte veins have been observed to be hosted by this rock.

**Plate 1: Typical Granite exposure at Liji Hill (N10°18.616' and E11°13.395')**

Microscopic study of the granite indicates the presence of quartz, orthoclase, microline, plagioclase, biotite, muscovite and accessory iron oxide and zircon. The quartz is colourless, with low relief and weak bireferengence. It occurs as subhedral to anhedral form and large crystals exhibit cracks and undergo undulose extinction. Quartz ranges in composition from 33% to 48% by volume. The orthoclase occurs as subhedral and tabular clourless crystals with low relief and weak birefringence. It shows light to dark grey first order interference colour. Sericitization have been observed in some crystals. Orthoclase ranges from 10% to 48% in composition. The microcline is colourless, with low relief, weak birefringence and tabular in form. It exhibit poly-synthetic twinning, while the plagioclase was determined based on extinction ($An_{15}$) corresponding to oligoclase shows albite twinning and is frequently zoned and has composition of 5% to 25%. Biotite occurs as brown to dark brown coloured mineral having high relief and strong birefringence. It exhibits anhedral form and strong pleochroism. The interference colour is dark brown. It ranges in composition from 3% to 15%. Muscovite is colourless with moderate relief. It is tabular in form and has perfect cleavage in one direction. It has moderate birefringence with pale green interference colour. It is about 1% to 10% in composition. Iron oxide occurs as disseminated accessory minerals in the rock, while zircon occurs as an inclusion in some orthoclase. The photomicrograph of the granite is presented in Plate 2.

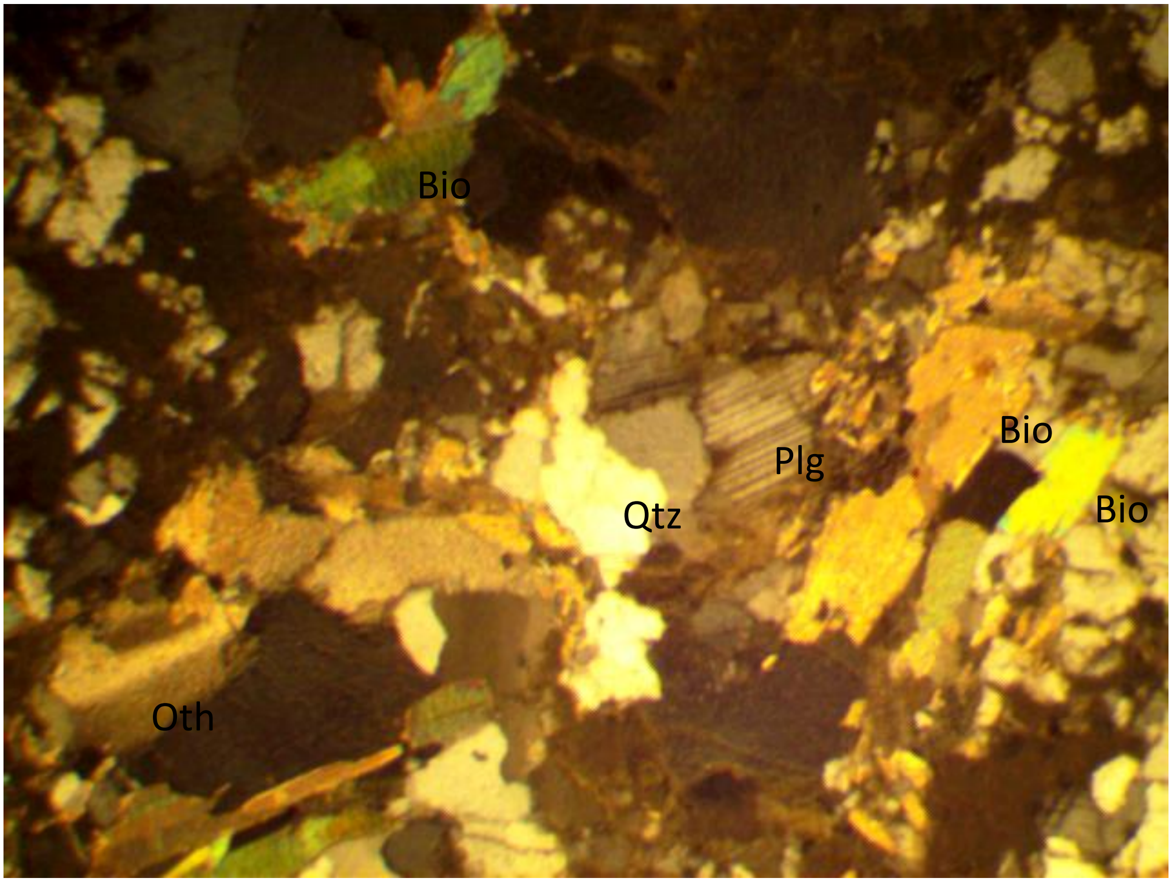


**Plate 2: Photomicrograph of granite showing: quartz-Qtz. Plagioclase-Plg. Biotite-Bio. Orthoclase-Oth. In crossed polarized light. Length of photograh= 6.7mm.**

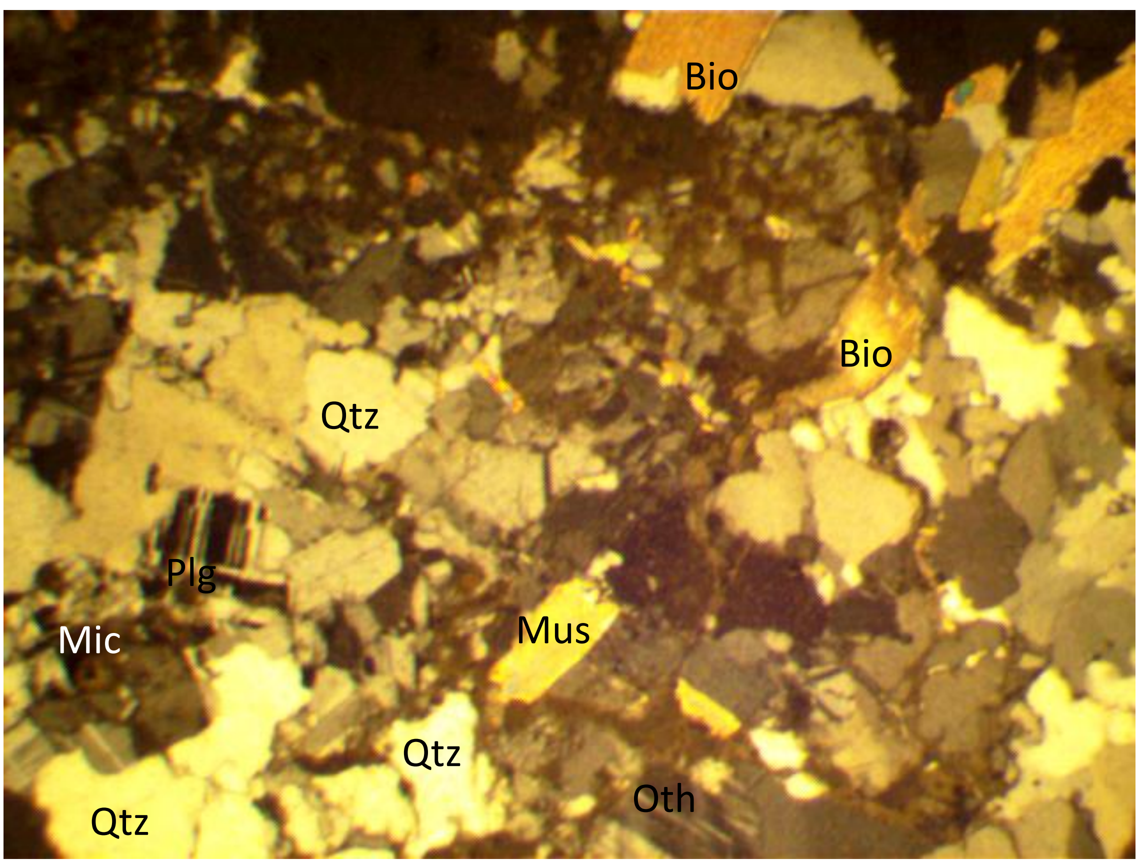


**Plate 3: Photomicrograph of granite showing: quartz-Qtz. Plagioclase-Plg. Biotite-Bio. Muscovite-Mus. Orthoclase-Oth. Microcline-Mic. In crossed polarized light. Length of photograph= 6.7mm**

***3.1.2 Pegmatite***

The pegmatite cross-cut the granitic rock in form of veins and as tabular large pegmatite body that have been reduced by weathering to boulders and fragments. A pegmatite vein measuring 1.5 – 3m wide and 250m long occur in the Liji hill where greenish coloured quartz are being mined, which are described by the artisanal miners as the 'Greencast' (Plate 4 and 5). The pegmatite occur whitish, pinkish to greenish in colour, very coarse grained in texture with wide sheets (3cm to 6.3cm wide) of muscovite that could be detached with ease. The principal mineralogy of this rock is essentially quartz, feldspar and muscovite. This rock also host baryte veins.


**Plate 4: Pegmatite with 'Green cast' (N10°18.715' and E11°13.506')**

Microscopic investigation reveals that the pegmatite consist essentially of quartz, plagioclase ($An_{11}$= Oligoclase), orthoclase and muscovite while biotite occur as an accessory and baryte as secondary mineral. The quartz appears colourless with low relief and weak birefringence. It is anhedral to subhedral in form with no cleavage but larger crystals are typified by uneven cracks. In composition it is 35% to 55%. The quartz also occurs as graphic intergrowth. Plagioclase is colourless with low relief and weak birefringence. Tabular in form and show repeated albite twinning, it is determined based on extinction angle to correspond to oligoclase ($An_{11}$). The orthoclase is colourless with low relief and weak birefringence. It is subhedral form and has dark grey to light grey first order interference colours with carlsbad twinning. It ranges from 33% to 40% by volume in the rock. The muscovite appears colourless with moderate relief and moderate birefringence. It is tabular in form with perfect cleavage in one direction. It has pale green to greenish-yellowish upper second order interference colours. The biotite is brown with high relief and strong birefringence. It is anhedral in form with perfect cleavage in one direction. It is strongly pleochroic with brown to dark brown interference colours and exhibit parallel extinction and has about 2% to 3% composition. Baryte is colourless with low relief and granular in form. It has perfect cleavage in three directions. It has weak birefringence and parallel extinction. It occurs in the pegmatite as veinlets filling minute fractures. Photomicrographs of pegmatite are presented in Plate 6.


**Plate 5: Pegmatite typified by Green cast (N10º18.639' and E11º13.432')**

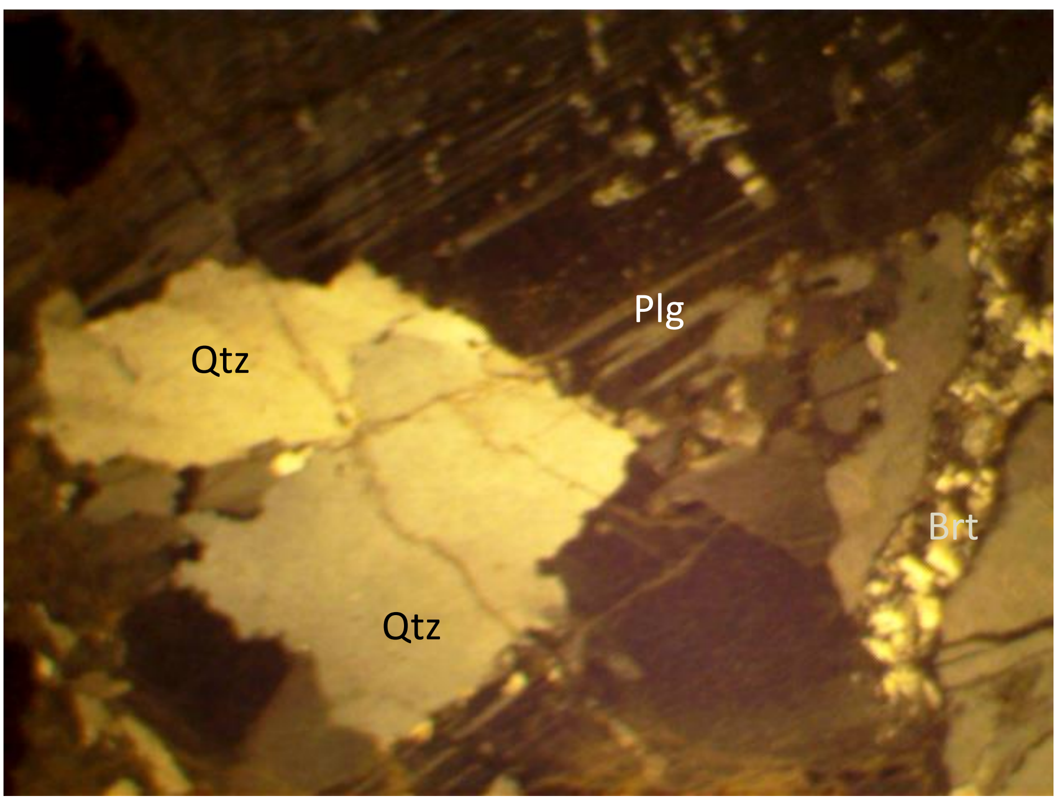


**Plate 6: Photomicrograph of pegmatite showing: Quartz-Qtz. Plagioclase-Plg. Baryte-Brt. In crossed polarized light. Length of photograph= 6.7mm**

### 3.2 The Cretaceous Sediments

The Cretaceous sediments constitute over 90% of the total rocks in the area (Fig. 3). Formations encountered are Bima Sandstone, Yolde Formation, Pindiga Formation and Gombe Sandstone.

#### *3.2.1 Bima Sandstone*

The Bima Sandstone surrounds and partly overlies the crystalline basement of Gombe and Liji hills (Fig. 3). The Bima sandstone lies directly and nonconformably on the Basement. It is whitish, pinkish and grayish coloured. The texture varies from fine-to-medium to coarse grained. The rocks are massive and thickly bedded, forming extensive hills that run from few meters to several kilometres in extent. Generally the rocks are poorly sorted and exhibit various structural features that include cross-bedding, joints and rarely micro quartz veins. Silicified varieties are common and argillaceous intercalations have been observed in the Gombe hill, and are believed to be the indurated shaly component of the Bima sandstone. Carter et al. (1963) reported similar lithology at Gombe area which includes very-coarse grained feldspathic sandstone, thin clays, shales and calcareous sandstones which indicate brief marine incursion during Albian time. Compositionally they are made up of predominantly quartz and feldspar with few samples containing mica. Weathering activities have affected this rock and breaks them to numerous boulders which roll to occupy plain areas. The Bima sandstone was observed to host baryte veins in some places.

**Plate 7: Typical Bima Sandstone showing bedding plane in Liji area**

Microscopic study indicates that the Bima sandstone is composed of quartz, orthoclase, microcline, biotite and iron oxide. The quartz range from 30% to 40% in composition and is colourless with low relief and weak birefringence. It is sub-angular to sub-rounded in form. The large grains are fractured and undergo undulose extinction while the smaller grains are less fractured and show parallel extinction. The orthoclase is colourless with low relief and weak birefringence. The form is sub-angular to sub-rounded with some being tabular in outline (Plate 6). The interference colour is grey to dark grey of first order. It ranges from 5% to 25% compositionally in the rock. Microcline is colourless with low relief and weak birefringence. The form is tabular and many are cracked, having perfect cleavages in two directions at right angle or near so, and exhibiting poly-synthetic twinning. The composition varies from 7% to 35% by volume in the rock. Biotite is brown in colour with high relief and strong birefringence. It occurs as sub-angular to sub-rounded forms and it is strongly pleochroic with brown to dark brown to yellowish second order interference colours. Biotite has about 2% to 15% compositional range. The iron oxide occur as reddish brown to dark sub-angular to sub-rounded grains, with few are well-round grains and constitute a composition of between 1% to 7% in the rock. The photomicrograph of Bima Sandstone is presented in Plate 6.

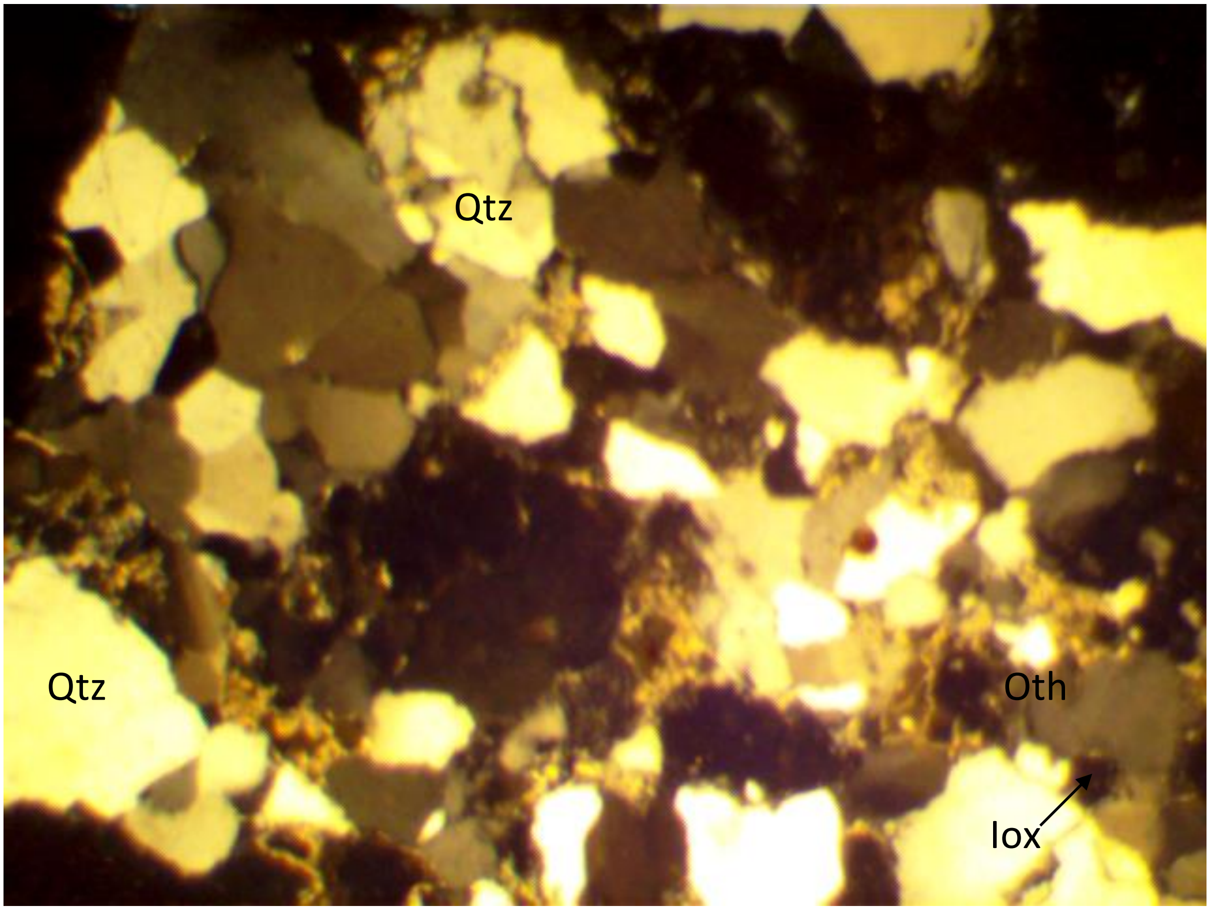


**Plate 8: Photomicrograph of Bima Sandstone showing: Quartz-Qtz. Orthoclase-Oth. Iron oxide-Iox. In crossed polarized light. Length of photograph= 6.7mm.**

***3.2.2 Yolde Formation***

In the Liji study area its occurrence is restricted to the south-western part in which it is surrounded by Bima sandstone (Fig. 3). The Formation consists of alternating sequence of sandstones, siltstones and mudstones, some of which are capped with minor ironstone. The Formation appears in whitish and brownish varieties. Texturally it is made-up of a medium to fine grained sandstones, consisting of mainly quartz, feldspars and traces of iron-oxides. Structurally it is laminated and cross-bedded.

In thin section the sandstone of the Yolde Formation consist of quartz, orthoclase, plagioclase, biotite, iron oxide and zircon. The quartz is colourless and fine to medium grained. It is sub-rounded to rounded in form and constitute about 30% to 55% compositionally. Orthoclase is colourless and sub-angular to sub-rounded in form. It shows carlsbad twinning and in composition it vary from 20% to 40% while plagioclase shows albite twinning. Plagioclase ranges from 5% to 7% by volume. The biotite is brown with high relief and strong birefringence and sub-angular to sub-rounded in form. It is srongly pleochroic and exhibit parallel extinction and compositionally range from 3% to 6% in the rock. The iron oxide is reddish in colour and sub-angular to irregular in form. The zircon is pale pinkish with very high relief and very strong birefringence. It occurs in short prismatic forms and exhibits pale tints of pink interference colour of the fourth order. It constitutes less than 1% by volume of the rock. The photomicrograph of Yolde Formation is given in Plate 7.

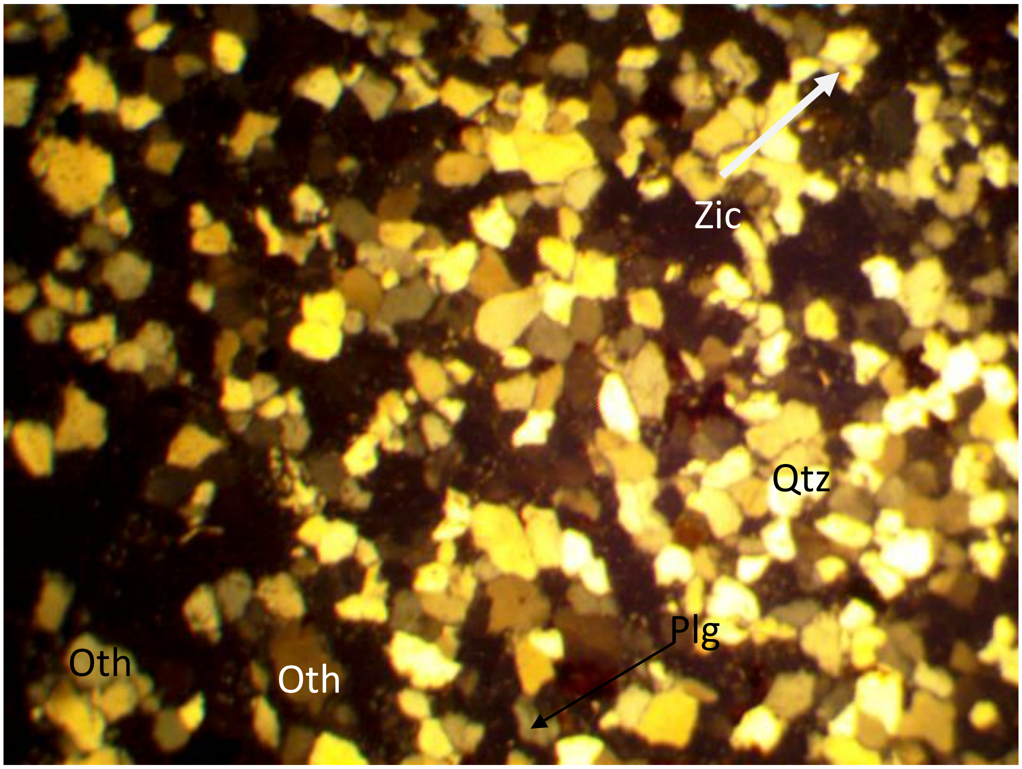


**Plate 9: Photomicrograph of Yolde sandstone showing: Quartz-Qtz. Plagioclase-Plg. Orthoclase-Oth. Zircon-Zic. In crossed polarized light. Length of photograph= 6.7mm**

***3.2.3 Pindiga Formation***

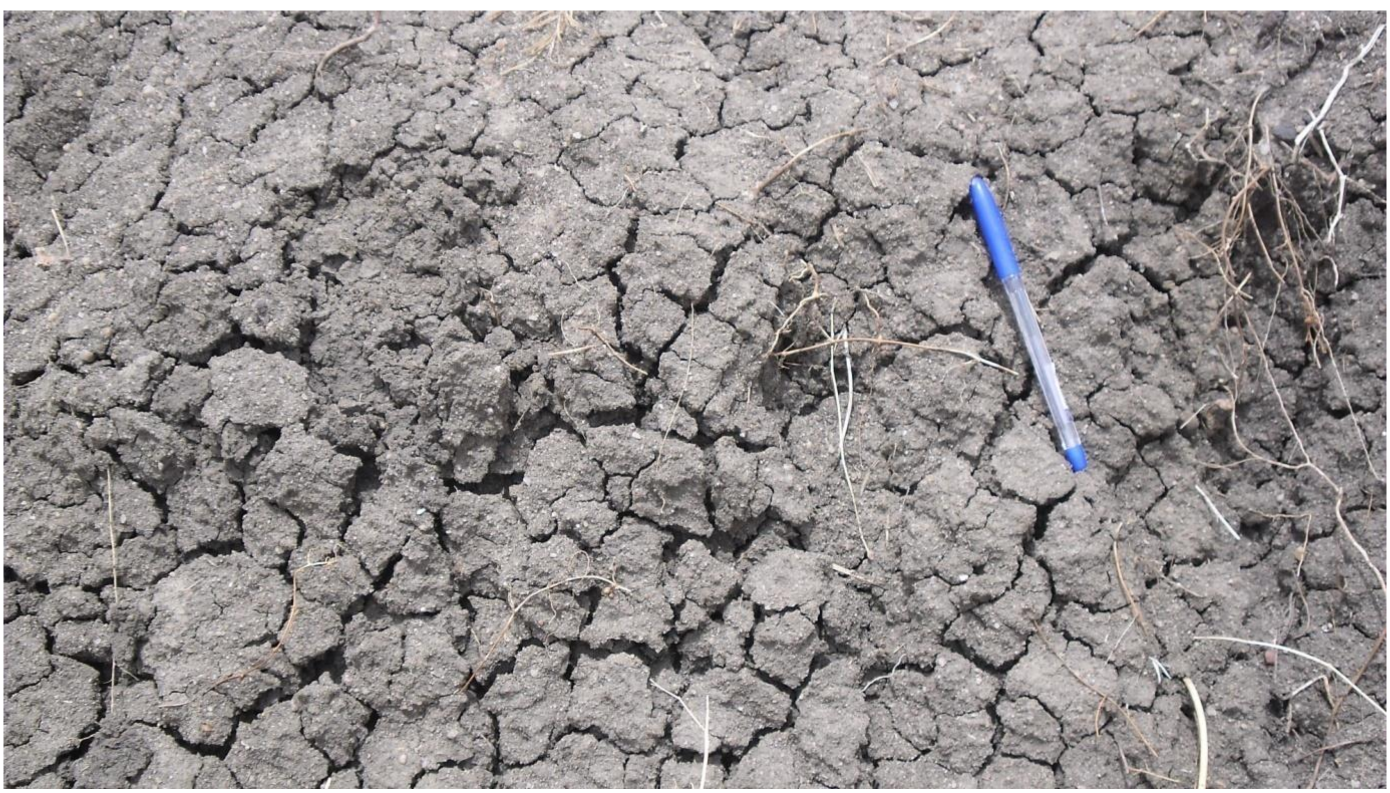

**Plate 10: Dessication cracks in shale of Kanawa member of the Pindiga Formation (N10°16.875' and E11°19.314')**

The Pindiga Formation occurs at the extreme south-eastern corner around Kwadon and Kunje, as well as the western half of the mapped area around Kurba and an area 3km south of Liji (Fig. 3). The Pindiga Formation is represented by Kanawa Member which

consists essentially of shale and minor bodies of limestone. The shale is dark coloured, friable which weather to a black cotton soil, fine grained and exhibits dessication crack which is its characteristic feature (Plate 10). The limestone is gray and brown in colour, massive and highly crystalline with fossiliferous varieties containing ammonites and bivalve faunas. Cracked limestone was located few meters south of Liji hill and south-west of Gombe hill. The crack may be due to compressional loading responsible for the creation of Gombe fault. In a location 1km south of Kurba, a petrified limestone was encountered. The field photograph of the limestone is presented in Plate 11.

**Plate 11: Limestone of the Kanawa member of Pindiga Formation (N10º19.706' and E11º12.685')**

In thin section the limestone is composed of calcite, dolomite, microcline, quartz and iron oxide. The calcite is cloudy and colourless, with high relief and strong birefringence. It is subhedral to euhedral in form, with perfect rhombohedral cleavage in two directions. It exhibits pearl grey higher order interference colour and have a polysynthetic twinning. In composition it ranges from 52% to 75% by volume. Dolomite is grey with high relief and strong birefringence. It has rhombohedral cleavage perfect in two directions and is subhedral to anhedral in form. The microcline is colourless with low relief and weak birefringence. It is tabular in form and exhibits cross hatched twinning. Compositionally it ranges from 12% to 20% by volume in the rock. Quartz is colourless, with low relief and weak birefringence. It is fine grained and show parallel extinction. It has composition varying from 3% to 5% by volume in the rock. The iron oxide is dark and irregular in form. It ranges compositionally from 1% to 5% by volume. The photomicrograph of limestone is given in Plates 10 and 11.

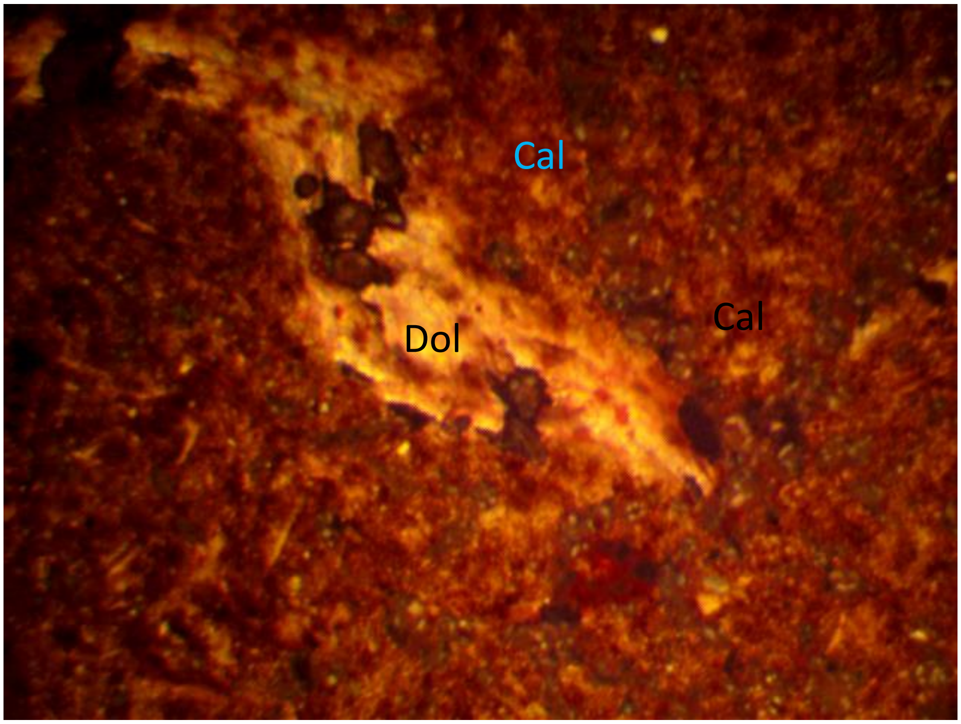


**Plate 12: Photomicrograph of Limestone showing: Calcite-Cal. Dolomite-Dol. In crossed polarized light. Length of photograph= 6.7mm**

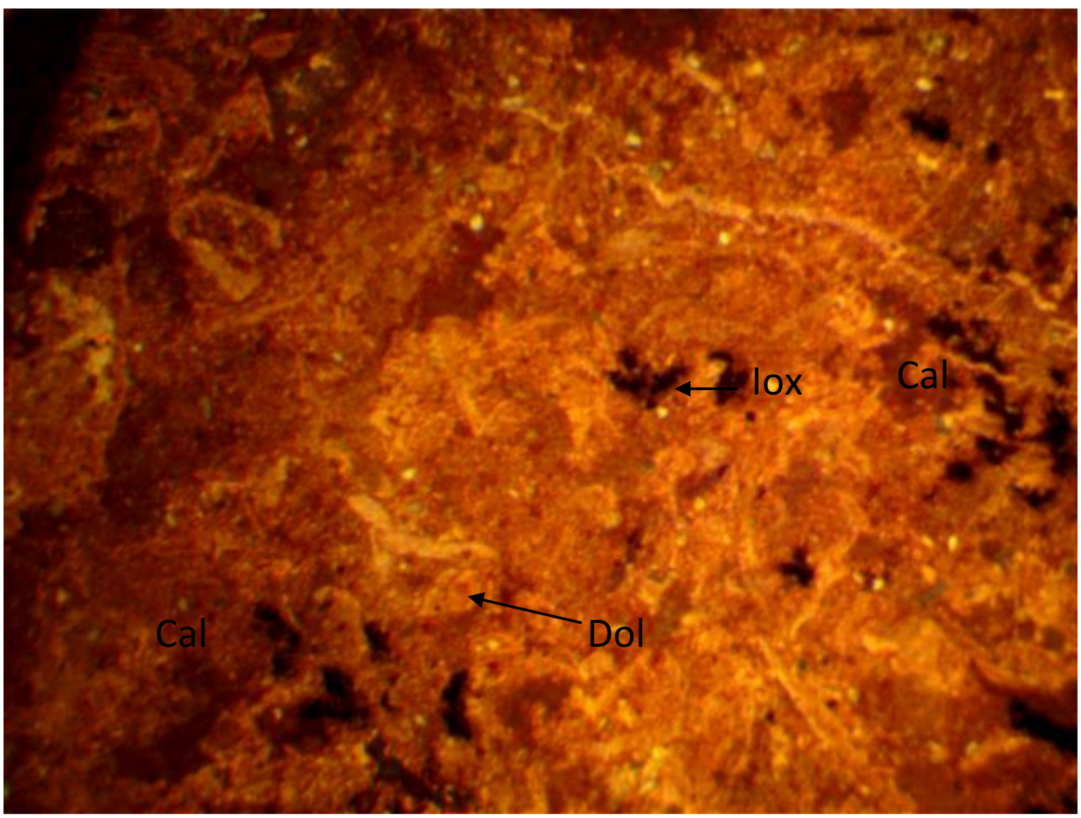


**Plate 13: Photomicrograph of Limestone showing: Calcite-Cal. Dolomite-Dol. In crossed polarized light. Length of photograph= 6.7mm**

### *3.2.4 Gombe Formation*

The Gombe Sandstone occurs around Wuro Umoru and occupies almost the entire eastern half of the mapped area (Fig. 3). It is a sequence of sandstone, siltstone, mudstone and ironstones (Plates 14-19). The Gombe sandstones are well exposed and form intermediate to low-lying gentle slope hills of restricted dimensions. Such hills are of numerous occurrences within the mapped area.

The sandstone units are generally pinkish, brownish to reddish in colour, fine to medium grained which are gritty, consisting essentially of quartz and feldspars and exhibits simple anticlinal folding (Plate 16). The siltstone units look pinkish coloured with fine grained texture having similar characteristic as the sandstone and exhibits liesegang rings structure at location K70 (10°19.435'N, 11°12.588'E) (Plate 15). The mudstone unit overlie the siltstone. It is creamy white in colour, very fine-grained texture which exhibit lamination and bioturbation. It is soft and friable having easily separable lamellae with no mineral grains visible in hand specimen. The ironstone unit is thin, dark brown, hard deposit that forms at the top of most outcrops of the Gombe Formation. It forms ferrogeneous iron capping to the formation and commonly breaks into fragments which litters the area. The ironstone is fine grained in texture with quartz and ferruginous minerals being the mineral composition (Plate 19).

**Plate 14: Section of sandstone unit of Gombe Formation (N10°18.743' and E11°18.351')**

**Plate 15: Liesegang rings on sandstone of Gombe Formation (N10°19.435' and E11°12.588')**

**Plate 16: Folded beds (outline) of Gombe Formation with mudstone and ironstone cap (N10º18.743' and 11º18.351')**

**Plate 17: Siltstone unit of Gombe Formation exhibiting lamination (N10º21.689' and 11º15.521')**

**Plate 18: Thick bed of mudstone unit of Gombe Formation (N10º18.206' and E11º14.799')**

**Plate 19: Ferruginized ironstone capping on Gombe Formation (N10º18.743' and 11º18.351')**

Microscopic investigation reveals that the Gombe sandstone contains quartz, feldspar, and iron oxide. The quartz is fine grained, colourless and sub-rounded in form. It undergo parallel extinction. The feldspar (orthoclase) is colourless fine grained, with low relief and weak birefringence. It is very difficult to resolve due to the fine nature of the grains. Iron oxide is dark irregular and fine grained.

It is sub-rounded to rounded in form non-pleochroic mineral. The photomicrograph of Gombe Sandstone Formation is presented in plates.

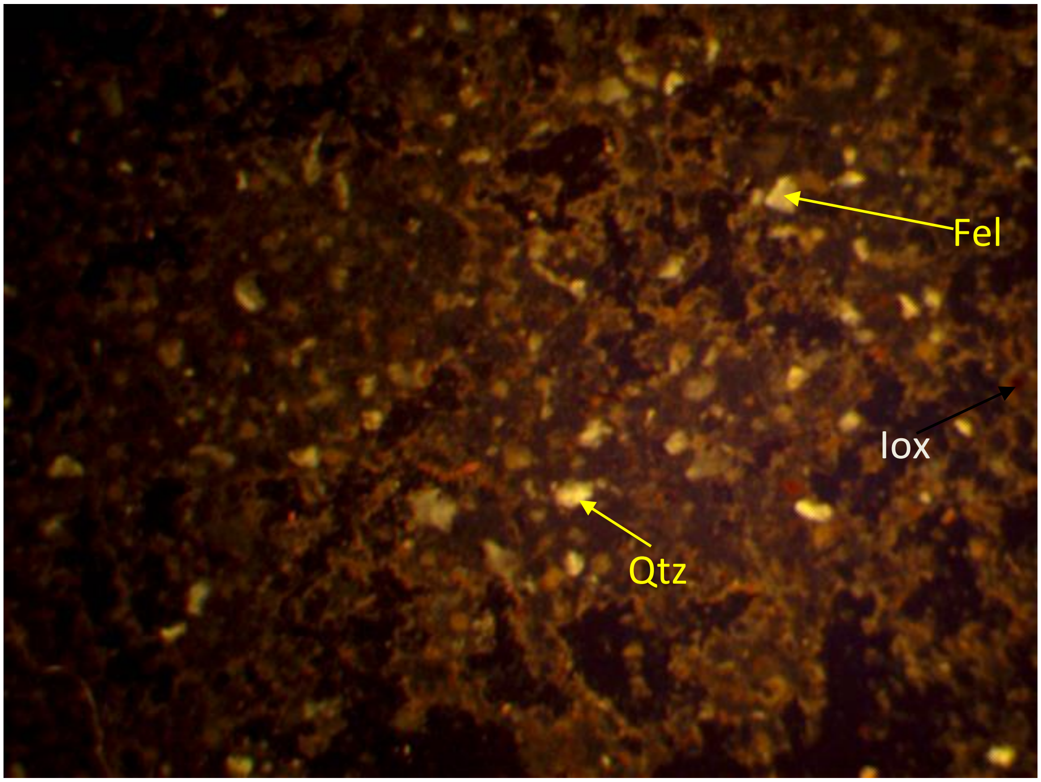


**Plate 20: Photomicrograph of Gombe sandstone showing: Quartz-Qtz. Feldspar-Fel. Iron oxide-Iox. Crossed polar. Length of photograph= 6.7mm.**

## 4. DISCUSSION

The geologic mapping of the Liji area was carried out and a geological map of the area was produced (Fig. 3). The mapping exercise revealed the occurrence of crystalline basement complex rock and Cretaceous sedimentary rocks. The basement rocks occur as inlier in two parts forming the prominent Liji and Gombe hills. The basement rock is composed of granite and pegmatite. The granite form steep sided hills and are generally pinkish and range from medium to coarse grained with quartz, feldspar and mica visible in hand specimen. Numerous quartz veins were observed to cut across the granitic rocks in many places. Microscopically the granite consist of quartz, orthoclase, microcline, plagioclase ($An_{15}$= Oligoclase), biotite, muscovite with accessory iron oxide and zircon. The pegmatite generally occurs as tabular body cross-cutting the granite. It is pinkish in colour with quartz, feldspar ± mica. Some varieties were observed to contain large muscovite sheets of 3 - 6.5cm. In some pegmatites, quartz are greenish in colour approaching gem quality, known as greencast locally and unlicenced mining activity for the green cast is ongoing in that area. In thin section the pegmatite consists of quartz, orthoclase, plagioclase ($An_{11}$= Albite), muscovite and biotite. The Cretaceous sedimentary rocks are represented by Bima and Yolde Formations, Kanawa member of Pindiga Formation and Gombe Formation. The Bima sandstone occurs as thickly bedded poorly sorted, highly indurated (with some samples silicified), massively feldspathic and cross-bedded sandstone that form hills. Argillaceous intercalations were encountered in the Gombe hill area which was believed to indicate brief marine incursion during Albian time (Carter *et al*., 1963; Joseph *et al*., 2007). Carter *et al*. (1963) reported similar lithology around Gombe area. Microscopic studies show quartz, orthoclase, microcline, biotite and iron oxide. Two generetions of quartz were observed; the first are larger, fractured and cracked and undergo undulose extinction while the second are smaller grains, less fractured and undergo parallel extinction. The Yolde Formation occurs as thin low-lying small outcrop exposed by river which grades into the Bima Formation. It is light in colour, medium to coarse grained sandstone consisting mainly of quartz and feldspars. Petrograhic investigation reveals the presence of quartz, orthoclase, plagioclase, biotite, iron oxide and zircon. The Kanawa member of the Pindiga Formation was encountered, consisting of shale and minor limestone bodies scattered within the shale as loose slabs, blocks and fragments. The shale is dark, fine grained and exhibit dessication cracks and weathers to cotton black soil. The limestone is grey, dense and massive; crystalline, fossiliferous and petrified varieties were encountered. Some limestone near the

Gombe inlier were noticed to be cracked and believed to have responded to the compressional loading that created the Gombe fault (Guiraud, 1990; Joseph *et al*., 2008). The fossiliferous varieties contain fossils recognized as bivalves and ammonites. Thin section studies indicate the presence of calcite, dolomite with accessory microcline, quartz and iron oxide. The Gombe Formation occurs as minor hills of small dimensions consisting of a sequence of sandstone, siltstone, mudstone and iron oxide which generally exhibits anticlinal folding, lamination and liesegang rings structural features. Microscopic studies indicate the presence of quartz, feldspars and iron oxide. The feldspars are too fine to be resolved.

## 5. CONCLUSION

The Liji area is typified by presence of granite and pegmatite members of Pan-African granitoid and Cretaceous sediments that include Bima, Yolde, Pindiga and Gombe Formations. The Basement rocks occur mainly as inliers surrounded by younger rocks and constitute about 7% of total area mapped while the remaining 93% were occupied by the sedimentary deposits. Baryte and greencast were found to be hosted by the basement rocks which mark mineralization of interest in the area. Petrography indicated that quartz is the dominant mineral in all the rocks except the limestone and iron oxide is least in abundance alongside zircon.

**Conflicts of Interest**

The authors declare no conflicts of interest.

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